LIVING WITH CLIMATIC VARIABILITY AND POTENTIAL GLOBAL CHANGE: CLIMATOLOGICAL ANALYSES OF IMPACTS ON LIVESTOCK PERFORMANCE

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Introduction

Livestock are produced in a variety of environments, some of which present considerable thermal challenges to productive performance and, in extreme cases, survival. Animal responses to such challenges are represented in Fig. 1, illustrating the effects of potential thermal stressors of varying intensity and duration, as well as elements of biological adaptation and recovery.

Biometeorology plays a key role in the assessment of climatic impacts and the development of rational environmental management of agricultural animals, under either current climate variability or with possible global change. This review presents results of some assessments of those impacts on animal agriculture (primarily in terms of performance, but including effects on mortality resulting from extreme events). Climatological data, as well as selected scenarios of global change, have been used in the analyses. The focus is primarily on performance losses associated with warm/hot weather, death losses from heat waves, and projected impacts of global warming used as specific examples for developing risk management considerations.

Impacts of Summer Weather Variability

Several livestock performance response models are now available, and have been used in conjunction with climatological records (e.g., Hahn and McQuigg, 1970a) to develop a series of reports over the past 30+ years, which evaluate the effects of weather on production (feed intake and efficiency; growth; milk production; etc.) and reproduction (e.g., Hahn and McQuigg, 1970b; Hahn and Osburn, 1969; Hahn, 1975; Hahn, 1995). One example will be cited, taken from Hahn and Nienaber (1976), which was an extension of a prior report (Hahn and Osburn, 1969).

Using a milk production decline algorithm for shaded dairy cows (Berry et al., 1964) and climatological data for nine United States locations, assessments of expected (50-percentile values) performance and the likely departures from the expected values were made on a probabilistic basis. Hourly records of drybulb and dewpoint temperatures for the summer period of June 1-September 30 were used to compute daily mean Temperature-Humidity Index (THI)[1]. Results were used to indicate isolines of expected milk production losses in the eastern two-thirds of the U.S. for cows normally producing 32 kg/day (Fig. 2). Percentile values were also calculated to indicate production variability expected as a result of weather fluctuations. Some 10th and 90th percentile values of production losses (kg/cow-season), respectively, were: Dallas TX, 416/586; Atlanta GA, 95/268; Dayton OH, 18/129; Columbia MO; 86/200; Oklahoma City OK, 159/330; Sacramento CA, 3/25; Sioux Falls SD, 13/91; Madison WI, 0/68; Massena NY, 0/47. Using Oklahoma City as an example, the expected milk production loss of 254 kg would be substantial (6.5% of the total 3904 kg for the 122-day summer period, varying from 4.1 to 8.4% based on the 10- and 90-percentile values).

Impacts Of Summer Weather Extremes

High environmental temperatures and lack of prior conditioning can result in catastrophic production and death losses for livestock. Heat waves[2] in particular can push vulnerable animals beyond their survival threshold limits; many examples can be cited of major death losses in the United States and elsewhere (e.g., dairy cows in southern California, 1977 [Oliver et al., 1979]; feedlot cattle in Nebraska, 1992 [Hahn and Nienaber, 1993], and 1999 [Mader et al., 2001]). A 1995 (July 10-15) heat wave in the midwestern United States resulted in more than 4000 feedlot cattle deaths in Iowa and Nebraska, as well as numerous human deaths in Chicago and elsewhere. During this heat wave event, there were extended periods during five days of the heat wave (July 10-14) when the THI values were 84 or above. One contributing factor to the cattle losses was the continuous exposure to THI values above 70, so there was no opportunity for recovery at night (an important element in coping with heat stress; Scott et al., 1983). Accompanying high solar radiation loads (clear to mostly clear skies) and low to moderate windspeeds were further contributing factors in the area of highest risk. For cattle in other locations with 20 or more daily THI-hrs in the "Emergency" category (THI ≥ 84) for only one or two days, the animal heat load was apparently dissipated with minimal or no mortality (Hahn, 1999). The economic toll from this heat wave event for cattle feeders in Iowa alone was estimated to be $28 million as a result of death and performance losses (Smiley, 1996).

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[1] The Temperature Humidity Index is a derived statistic (Thom, 1959):

$$THI = t_{db} + 0.36\, t_{dp} + 41.2$$

where t_{db} = drybulb air temperature, °C
t_{dp} = dewpoint temperature, °C

THI values also serve as the basis for the Livestock Weather Safety Index (LWSI; LCI, 1970) and have been used by the U.S. National Weather Service for advisories (USDC-ESSA, 1970): Normal, ≤ 74; Alert, 75-78; Danger, 79-83; Emergency, ≥ 84. For additional discussion of the THI and its applicability, see Hahn (1995) and Eigenberg et al. (2002). The use of thermal indices, including the THI, for livestock environmental management is reviewed by Hahn et al., 2003.

[2] According to the Glossary of Meteorology (AMS, 1989), a heat wave is "a period of abnormally uncomfortable hot and usually humid weather of at least one day duration, but conventionally lasting several days to several weeks..." An operational definition often used for a heat wave is three to five successive days with maximum temperatures above a threshold, such as 32°C.

Retrospective analysis of hourly climatic records during the 1995 heat wave event was used to evaluate characteristics of heat waves (e.g., intensity, duration, recovery time) that cause feedlot cattle deaths; the results, in terms of daily THI-hrs at or above the LWSI thresholds for the Alert, Danger, and Emergency categories, provide a valuable approach to environmental management practices (Hahn and Mader, 1997). This THI-hrs analysis of the 1995 heat wave and others have reinforced the LWSI thresholds for categories of risk, and support an environmental profile for single heat wave events that create conditions likely to result in deaths of *Bos-taurus* cattle in feedlots: 15 or more THI-hrs per day for three or more successive days at or above a base level of 84 (Emergency category of the LWSI) with minimal or no nighttime recovery opportunity. Death losses can be expected if shade, precautionary wetting, or other relief measures are not provided during such conditions. Conditions in the "Danger" category of the LWSI also may cause mortality in highly vulnerable animals (e.g., new entrants to the feedlot; those at or near market weight; animals not yet acclimated to hot weather; sick animals, especially with respiratory problems). Successive heat waves with intervening cool periods can create excessive heat loads and potentially lethal conditions for cattle even when the conditions during secondary heat waves are comparatively moderate. This is likely a result of increased feed intake during the cool periods. It should be further noted that costs associated with death losses, while drastic, are often greatly surpassed economically by performance losses (growth, efficiency) of surviving cattle (Balling, 1982).

Impacts of Global Change

Several assessments of global change impacts on livestock performance have been made in recent years, using the same or refined algorithms mentioned in the prior section. These assessments have been primarily in terms of summertime impacts (e.g., Hahn et al., 1992; Klinedinst et al., 1993; Frank et al., 2001a,b). Global change scenarios used in the earlier assessments were the GISS, GFDL, and UKMO global circulation models, each with doubled CO2 compared to the base period.

More recent scenarios are those of the Canadian Centre for Climate Modeling and Analysis (CGCMI; CCCMA, 2000) and Hadley Centre for Climate Prediction and Research (Hadley; NCAR 2000). These scenarios have been used in conjunction with more biologically-relevant algorithms emphasizing voluntary feed intake (VFI) and subsequent animal growth or milk production for comparison with climatological records for a base period (1975-1995). Full descriptions of the swine (growing-finishing animals), beef (feeder cattle) and dairy (milk production) animal models, and the CGCMI and Hadley climate scenarios used, are available in Frank et al.(2001b). In general, for the central U.S., the CGCMI projects an increase in air temperature, a slight decrease in precipitation, little change in specific humidity, and a slight reduction in wind speed over the period 1975 to 2100 (CCCMA, 2000), while Hadley predicts an increase in summer air temperature but a more pronounced decrease in precipitation (NCAR, 2000).

Briefly, the CGCMI and Hadley scenarios were used to develop daily output values representative of potential climate change from June 1 through October 31 (153 days) in the years 2030 and 2090 for specific areas of the United States, based on daily climate scenario values for a 3.75 degree grid (approximately 410 km N-S by 222 km E-W in the central U.S.). The impacts on daily meat or milk production were then computed using the algorithms for growth (growing-finishing swine; feeder cattle) or milk production (milk cows), and represented by the resultant number of days to reach a target weight (growing animals) or kg milk produced per cow for the 153-day period. Results can be summarized as follows: for swine, days to slaughter weight associated with the CGCMI 2030 scenario increased an average of 3.7 days from the baseline (mean of 1975-1995) of 61.2 days. Potential seasonal losses under this scenario averaged 6%, costing swine producers in the MINK (Missouri, Iowa, Nebraska, Kansas) region \$12.4 million. Losses associated with the Hadley 2030 scenario are projected to be less severe, with increased time to slaughter weight averaging 1.5 days or 2.5%, costing producers \$5 million. For feeder cattle, time to slaughter weight associated with the CGCMI 2030 scenario increased 4.8 days (above the 127-day average baseline value), or 3.8%, costing producers \$43.9 million. For the Hadley model, the additional days for feeder cattle growth were 2.8 days (2.2%). The projected seasonal reduction in milk production by dairy cows based on the CGCMI model was 2.2% (105.7 kg/cow), for a \$28 million loss. Milk production losses associated with the Hadley scenario averaged 2.9%, with an estimated cost to producers of \$37 million.

Outside the MINK region of the U.S., the CGCMI scenario projects severe losses in swine growth for the south central and southeastern regions, but little effect on production in the northwest. Nationally, increased time to slaughter weight associated with the 2030 scenario ranged from a 3.4% decrease to a 10.3% increase in days to slaughter. The Hadley scenario projected much less severe losses in most locations. For feeder cattle, time to slaughter weight for the CGCMI 2030 scenario ranged from -0.1% to 6.2% of baseline values. Climate change effects based on the Hadley 2030 scenario again were less severe than the CGCMI, but were more consistent across regions; days on feed increased two to three days (1.6 to 2.4%) above baseline, as shown in the isolines of Fig. 3.

This figure also illustrates geographic shifts in days on feed from the baseline to 2030 and 2090 projections for the Hadley scenario. The projected shifts are quite substantial in some areas, mostly in the central U.S., where many cattle feedlots are located. As a specific example, the 126-day isoline is shifted to the N and E by about 200 miles for the 2030 scenario projection; such shifts can lead to significant decreases in production efficiency and profitability at a given location, unless feedlot managers apply countermeasures such as environmental modification or use of more-adapted animals. For dairy cows, trends in percentage losses of milk production were similar to the percent increase in feeder cattle days on feed, although some regional differences were observed.

Changes in climate induced by increasing CO2 levels are primarily manifested as increases in air temperature, which reduces livestock production during the summer season. Both climate change scenarios used in this analysis suggest substantial production losses for conditions associated with elevated CO2, but the degree of loss is not always consistent between the scenarios. Projected production losses are larger under the CGCMI compared to the Hadley modeled climates, which concurs with the observation that the CGCMI scenario predicts larger warm season temperature increases during the period evaluated. In general, across the entire United States, the percent increase in days to market for swine and beef, and the percent decrease in dairy milk production, for the 2030 scenarios averaged 1.2, 2.0, and 2.2%, respectively, using the

CGCMI model, and 0.9, 0.7, and 2.1%, respectively, for the Hadley model. For the 2090 scenario, respective changes averaged 13.1, 6.9, and 6.0% for the CGCMI model and 4.3, 3.4, and 3.9% using the Hadley model.

Summary

Summer weather challenges agricultural animals in many regions of the world, whether a result of current natural variability or potential global change. A consequence of heat stress associated with summer conditions is reduced performance, and in some cases, death from extreme events (e.g., heat waves). In terms of environmental management, the impacts can be reduced by recognizing the adaptive ability of the animals and by proactive application of appropriate counter-measures (sunshades, evaporative cooling by direct wetting or in conjunction with mechanical ventilation, etc.). Quantification of the impacts of normal summer weather and potential global change allows livestock producers to gain a better understanding of the magnitude of production and death losses in both situations. Projected economic losses resulting from climate-induced reductions in production may justify mitigation through changes in management practices.

Specifically with regard to potential climate change, the capabilities of livestock managers to cope with the effects are quite likely to keep up with the projected rates of change in global temperature and related climatic factors. However, coping will entail costs such as application of environmental modification techniques, use of more suitably adapted animals, or even shifting animal populations. Assessment of potential economic impacts associated with global change on key areas of animal agriculture needs to be made available for use in allocating strategic adjustments and resources to minimize adverse effects on socioeconomic stability.

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References

1. AMS., 1989. Glossary of Meteorology, 5th Edition. Am. Meteorological Society. Boston, MA.
2. Balling, R.C., Jr., 1982. Weight gain and mortality in feedlot cattle as influenced by weather conditions: refinement and verification of statistical models. Rept. 82-1. Center for Agric. Meteor. and Climatology. Univ. of Nebraska, Lincoln, NE.
3. Berry, I.L., Shanklin, M.D., Johnson, H.D., 1964. Dairy shelter design based on milk production decline as affected by temperature and humidity. Trans. ASAE 7:329-331.
4. Canadian Centre for Climate Modeling and Analysis, 2000. www.cccma.bc.ec.gc.ca/data/cgcml/cgcml_daily_data.html.

5. Eigenberg, R.A., Brown-Brandl, T.A., Nienaber, J.A., Hahn, G.L., 2002. Dynamic response of feedlot cattle to shade and no-shade. ASAE Paper 024050. St. Joseph, Mich.:ASAE.
6. Frank, K.L., Mader, T.L., Harrington, J.A. Jr., Hahn, G.L., Davis, M.S., 2001a. Climate change effects on livestock production in the Great Plains. Proc., 6th Int'l. Livestock Environ. Sympos: 351-8. ASAE Public. 701P0201, St. Joseph, MI.
7. Frank, K.L., Mader, T.L., Harrington, J.A. Jr., Hahn, G.L., Davis, M.S., Nienaber, J.A., 2001b. Potential climate change effects on warm-season production of livestock in the United States. ASAE Paper 01-3042. St. Joseph, Mich.:ASAE.
8. Hahn, LeRoy, 1976. Rational environmental planning for efficient livestock production. Biometeorology 6 (Part II):106-114. (Supplement to Int'l. J. of Biomet., Vol. 20).
9. Hahn, G.L., 1995. Environmental management for improved livestock performance, health and well-being. Japanese Jour. of Livestock Management 30(3):113-12.
10. Hahn, G.L., 1999. Dynamic responses of cattle to thermal heat loads. J. Anim. Sci. 77:(suppl. 2):10-12.
11. Hahn, G.L., Klinedinst, P.L., Wilhite, D.A., 1992. Climate change impacts on livestock production and management. ASAE Paper No. 92-7037. St. Joseph, Mich.:ASAE.
12. Hahn, G.L., Mader, T.L., 1997. Heat waves in relation to thermoregulation, feeding behavior and mortality of feedlot cattle. Proc., 5th Int'l. Lvstk. Environ. Symp: 563-571. St. Joseph, Mich.:ASAE.
13. Hahn, G.L., Mader, T.L., Eigenberg, R.A. 2003. Perspective on development of thermal indices for animal studies and management, pp. 31044, In: Interactions Between Climate and Animal Production, (Eds. N. Lacetera, U. Bernabucci, H.H. Khalifa, B. Ronchi, and A. Nardone), EAAP Tech. Series No. 7, Wageningen Academic Publishers, The Netherlands (ISSN 1570-7318).
13. Hahn, G.L., McQuigg, J.D., 1970a. Evaluation of climatological records for rational planning of livestock shelters. Agric. Meteorology 7(2):131-141.
14. Hahn, G.L., McQuigg, J.D., 1970b. Expected production losses for lactating Holstein dairy cows as a basis for rational planning of shelters. Int'l. J. of Farm Bldgs. Res. 4:2-8.
15. Hahn, LeRoy, Nienaber, J.A., 1976. Summer weather variability and livestock production. ASAE Paper 76-1003. St. Joseph, Mich.:ASAE.
16. Hahn, G.L., Nienaber, J.A., 1993. Characterizing stress in feeder cattle. Beef Research Prog. Rept. No. 4 (ARS-71):146-148. US MARC, ARS, USDA.
17. Hahn, G.L., Osburn, D.D., 1969. Feasibility of summer environmental control for dairy cattle based on expected production losses. Trans. ASAE 12(4):448-451.
18. Hubbard, K., 1994. Spatial variability of daily weather variables in the high plains of the USA. Ag & Forest Meteorology 68:29-41.
19. Klinedinst, P.L., Wilhite, D.A., Hahn, G.L., Hubbard, K.G., 1993. The potential effects of climate change on summer season dairy cattle milk production and reproduction. Climatic Change 23:21-36
20. LCI., 1970. Patterns of transit losses. Livestock Conservation, Inc., Omaha, NE.
21. Mader, T.L., Hungerford, L.L., Nienaber, J.A., Buhman, M.J., Davis, M.S., Hahn, G.L., Cerkoney, W.M., Holt, S.M., 2001. Heat stress mortality in Midwest feedlots. Abstract 4, pg 2. ASAS, ADSA, DesMoines, IA.
22. NCAR, 2000. http://www.cad.ucar.edu/vempa/.
23. Oliver, J.C.,Hellman, H.M., Bishop, S.E., Pelissier, C.L., Bennett, L.F., 1979. Heat stress survey. Calif. Agric. 33:6-8.

24. Scott, I.M., Johnson, H.D., Hahn, G.L., 1983. Effect of programmed diurnal temperature cycles on plasma thyroxine level, body temperature, and feed intake of Holstein dairy cows. Int'l. J. Biomet. 27(1):47-62.
25. Smiley, J., 1996. "Killer heat cost feeders $28 million." Omaha World-Herald Midlands Edition, Mar. 7.
26. Thom, E.C., 1959. The discomfort index. Weatherwise 12:57-59.
27. USDC-ESSA, 1970. Livestock hot weather stress. Central Regional Operations Manual Letter 70-28. Environmental Sciences Services Admin., U.S Dept. Commerce, Kansas City, MO.

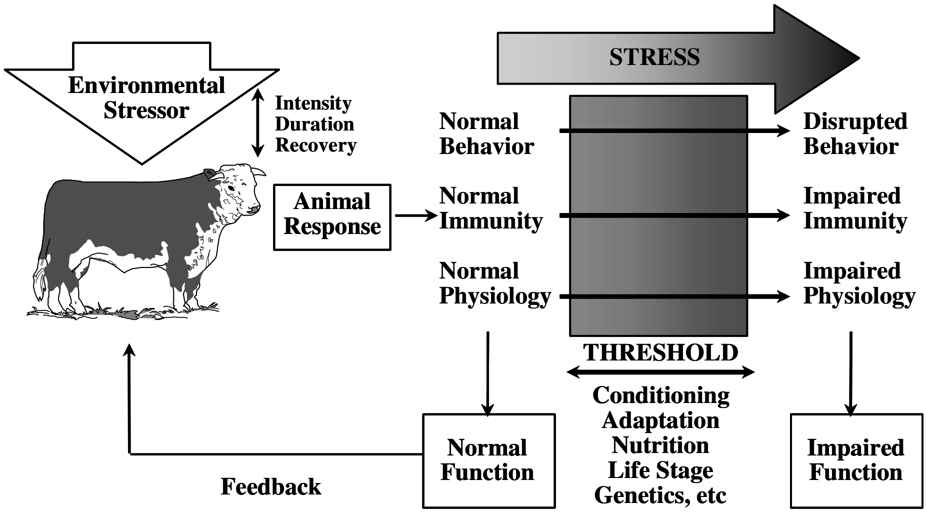

Figure 1. Responses of an animal to potential environmental stressors can lead to reduced performance, health and well-being. (adapted from Hahn and Morrow-Tesch, 1993).

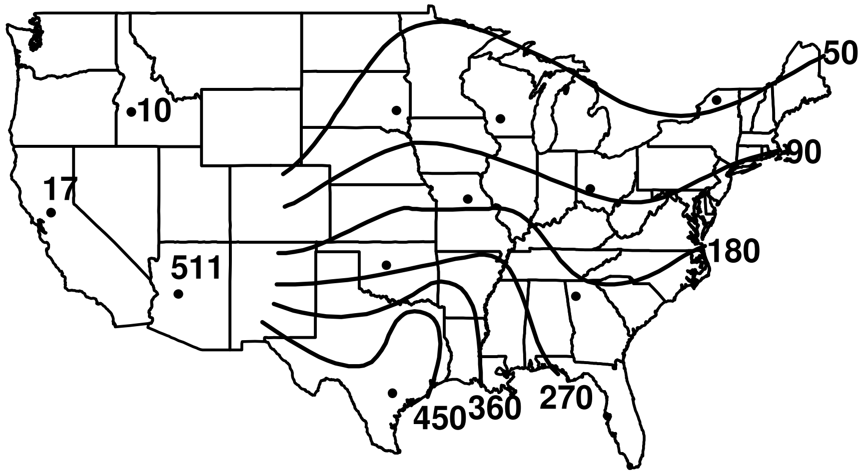

Figure 2. Expected milk production losses for dairy cows (kg/cow) with a normal production level of 32 kg/day during the 122-day (June 1-September 30) summer season (Hahn and Osburn, 1969).

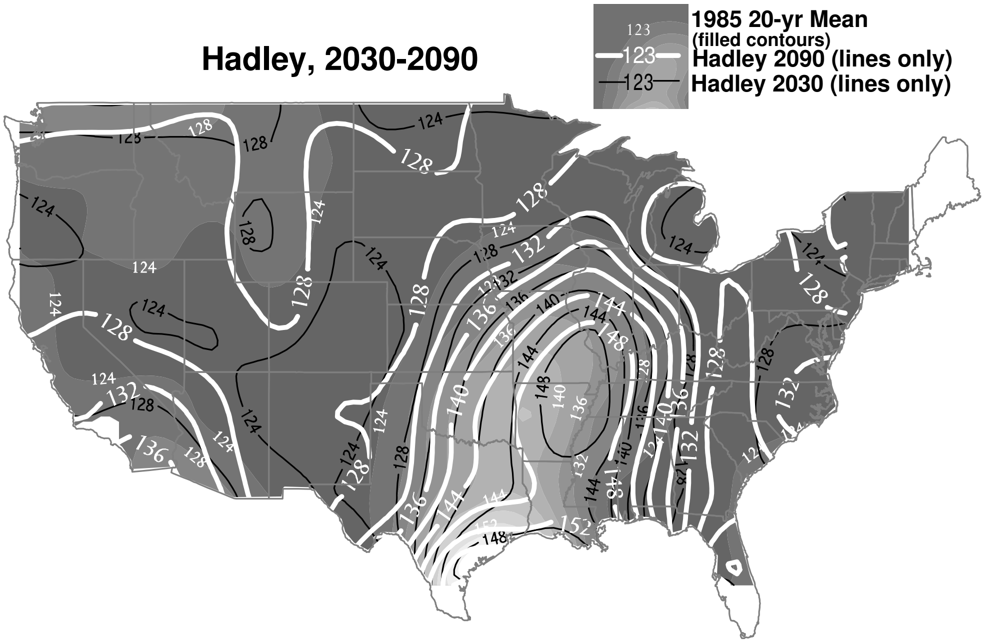

Figure 3. Days on feed required for feeder cattle to grow from 350 to 550 kg body weight, as estimated based on 1975-1995 climate data (1985 mean; shaded background contours), and as projected by the Hadley scenario for the years 2030 and 2090 (see text for further discussion).